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SPECIFIC HEAT RATIOS AND ISENTROPIC EXPONENTS FOR CONSTANT-VOLUME COMBUSTION OF STOICHIOMETRIC MIXTURES OF HYDROGEN-OXYGEN DILUTED WITH HELIUM HYDROGEN

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FOREWORD

This interim technical report was prepared by Andre Benoit, University of Toronto, Canada on Contract AF33(615)-2766 for the Aerospace Research Laboratories, Office of Aerospace Research, United States Air Force. The research reported herein was accomplished on Task 7065-0015, "Fluid Dynamics Facilities Research" of Project 7065, "Aerospace Simulation Techniques Research" under the technical cognizance of Mr. John Goresh of the Fluid Dynamics Facilities Research Laboratory of ARL.

The author wishes to express his thanks to Dr. G. N. Patterson for the opportunity to complete this work.

He is also grateful to Dr. I. I. Glass who suggested the study reported herein, and to Professor J. Meinguet for the opportunity to perform the numerical calculations at the "Centre de Calcul Numerique" of the University of Louvain.

ABSTRACT

This note is complementary to UTIAS Technical Note No. 85, "Thermodynamic and Composition Data for Constant-Volume Combustion of Stoichiometric Mixtures of Hydrogen-Oxygen Diluted with Helium or Hydrogen", by A. Benoit. It includes the calculation of the equilibrium specific heats, the equilibrium specific heat ratios, the isentropic exponents, and the corresponding values of the speeds of sound. For convenience, the final-to-initial temperature ratio and the final-to-initial pressure ratio have also been included in the present tables. The results are presented for helium and hydrogen dilution respectively.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

NOTATION

a	equilibrium speed of sound (m sec^{-1})
a_1	frozen speed of sound (m sec^{-1})
a^*	fictitious speed of sound (m sec^{-1}) defined by (53) (*)
a_{ik}	coefficients appearing in the linearized system ((15) to (17)) and given by relations ((18) to (29)).
b_{ik}	coefficients appearing in the linearized system ((30) to (31)) and given by relations ((32) to (37))
B_k	functions of p and T defined by (9) and (10)
C_p	molar equilibrium specific heat at constant pressure (cal $mole^{-1}$ $^oK^{-1}$) defined by (42)
C_{p_1}	molar frozen specific heat at constant pressure (cal $mole^{-1}$ $^oK^{-1}$) defined by (40)
C_{v_1}	molar frozen specific heat at constant volume (cal $mole^{-1}$ $^oK^{-1}$)
d	function of p and T defined by (39)
e	function of p and T defined by (36)
H	molar enthalpy (cal $mole^{-1}$) including sensible enthalpy and chemical energy at 0^oK for gas state
K	equilibrium constant based on partial pressures for reaction of formation from elements in gas state. The subscripts, 1, 2, 3 and 4 refer respectively to the formation of H_2O, OH, H_2 and O_2
m	number of moles of diluting hydrogen per mole of oxygen in reactants

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(*) (53) refers to equation (53) etc.

n	number of moles of helium per mole of oxygen in reactants
n_j	number of moles of species "j" in reaction products per mole of oxygen in reactants
n_i	total number of moles of reactants per mole of oxygen in reactants ($n_i = m + n + 3$)
n_f	total number of moles of products per mole of oxygen in reactants ($n_f = \sum_{j=1} n_j$)
p	pressure of products of reaction (atm)
p_i	pressure of reactants (atm)
R	universal gas constant (1.98718 cal mole^{-1} $^{o}K^{-1}$)
R_o	universal gas constant (8314. m^2 sec^{-2} $^{o}K^{-1}$ gr)
T	absolute temperature (^{o}K)
U	molar internal energy of reaction products (cal mole^{-1})
U_i	molar internal energy of reactants (cal mole^{-1})
γ	isentropic exponent defined by (44)
γ_1	frozen specific heat ratio defined by (49)
γ^*	equilibrium specific heat ratio defined by (47)
μ	molecular weight of products of reaction (gr. mole^{-1})
μ_1	molecular weight of reactants (gr. mole^{-1})
ν_j	molar fraction of species "j" in products of reaction

Subscripts

i	refers to the reactants

j	refers to species "j" according to the correspondence

1	for H_2O
2	for OH
3	for H_2
4	for O_2
5	for H
6	for O
7	for He

p	at constant pressure
s	at constant entropy
v	at constant volume

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1. INTRODUCTION

In order to complete the work on constant-volume combustion reported in Ref. 1, it was felt that the equilibrium quantities such as the specific heat, specific heat ratio, isentropic exponent and the equilibrium speed of sound should be computed and incorporated in the results. The same source of thermodynamic data was used (Ref. 2), but all the thermodynamic functions including the equilibrium constants were introduced in the program in the form of best-fitted analytical functions.

Instead of using the method of solution described previously (Ref. 1), the final thermodynamic conditions were obtained through an iteration procedure based on the linearization of the equations (Newton-Raphson iteration). This, at the same time, provided a verification of the results.

2. BASIC EQUATIONS

The general assumptions under which the calculations are performed have been described in Ref. 1.

The initial mixture

$$(2H_2 + O_2) + m\,H_2 + n\,He$$

at temperature T_i and the pressure p_i, is transformed to give $n_1\,H_2O + n_2\,OH + n_3H_2 + n_4\,O_2 + n_5\,H + n_6\,O + n_7\,He$, at temperature T and pressure p. The symbols H_2O, OH, etc. represent one mole of H_2O, one mole of OH, etc. The equilibrium equations combined with the equations of conservation of mass of each chemical element yield the following equations:

$$B_1\nu_5^2\nu_6 + B_2\nu_5\nu_6 + B_3\nu_5^2 + B_4\nu_6^2 + \nu_5 + \nu_6 + \frac{n}{n_f} - 1 = 0 \quad (1)$$

$$2B_1\nu_5^2\nu_6 + B_2\nu_5\nu_6 + 2B_3\nu_5^2 + \nu_5 - \frac{2(2+m)}{n_f} = 0 \quad (2)$$

$$E_1\nu_5^2\nu_6 + B_2\nu_5\nu_6 + 2B_4\nu_6^2 + \nu_6 - \frac{2}{n_f} = 0 \quad (3)$$

and

$$\nu_1 = K_1\nu_5^2\nu_6\,p^2 \quad (4)$$

$$\nu_2 = K_2\nu_5\nu_6\,p \quad (5)$$

$$\nu_3 = K_3\nu_5^2\,p \quad (6)$$

$$\nu_4 = K_4\nu_6^2\,p \quad (7)$$

$$\nu_7 = \frac{n}{n_f} \tag{8}$$

from which the composition can be determined when the temperature and pressure are known. In these relations, the ν's represent the molar concentrations, the K's are the equilibrium constants based on partial pressures and the subscripts of the K's refer to the following compounds: 1 to H_2O, 2 to OH, 3 to H_2 and 4 to O_2.
The B's are written for:

$$B_1 = K_1 p^2 \tag{9}$$

$$B_j = K_j p \quad (j = 2, 3, 4) \tag{10}$$

The two complementary equations required to determine the final pressure and temperature express the conservation of density and energy, i.e.,

$$\rho = \rho_i \tag{11}$$

or

$$\frac{p}{p_i} = \frac{T n_f}{T_i n_i} \tag{12}$$

and

$$n_f U = n_i U_i \tag{13}$$

or

$$n_f (H - RT) = n_i (H_i - RT_i) \tag{14}$$

3. METHOD OF SOLUTION

Equations (1) to (3) are linearized to provide a system from which ν_5, ν_6 and n_f^{-1} are determined for any set of values, p, T,

$$a_{11}\delta\nu_5 + a_{12}\delta\nu_6 + a_{13}\delta\left(\frac{1}{n_f}\right) = a_{10} \tag{15}$$

$$a_{21}\delta\nu_5 + a_{22}\delta\nu_6 + a_{23}\delta\left(\frac{1}{n_f}\right) = a_{20} \tag{16}$$

$$a_{31}\delta\nu_5 + a_{32}\delta\nu_6 + a_{33}\delta\left(\frac{1}{n_f}\right) = a_{30} \tag{17}$$

The coefficients a_{ij} are readily obtained

$$a_{11} = 2B_1\nu_5\nu_6 + B_2\nu_6 + 2B_3\nu_5 + 1 \tag{18}$$

$$a_{12} = B_1 \nu_5^2 + B_2 \nu_5 + 2B_4 \nu_6 + 1 \tag{19}$$

$$a_{13} = n \tag{20}$$

$$a_{10} = -(B_1 \nu_5^2 \nu_6 + B_2 \nu_5 \nu_6 + B_3 \nu_5^2 + B_4 \nu_6^2 + \nu_5 \nu_5 + \frac{n}{n_f} - 1) \tag{21}$$

$$a_{21} = 4B_1 \nu_5 \nu_6 + B_2 \nu_6 + 4B_3 \nu_5 + 1 \tag{22}$$

$$a_{22} = 2B_1 \nu_5^2 + B_2 \nu_5 \tag{23}$$

$$a_{23} = -2(2 + m) \tag{24}$$

$$a_{20} = -(2B_1 \nu_5^2 \nu_6 + B_2 \nu_5 \nu_6 + 2B_3 \nu_5^2 + \nu_5 - \frac{2(2+m)}{n_f}) \tag{25}$$

$$a_{31} = 2B_1 \nu_5 \nu_6 + B_2 \nu_6 \tag{26}$$

$$a_{32} = B_1 \nu_5^2 + B_2 \nu_5 + 4B_4 \nu_6 + 1 \tag{27}$$

$$a_{33} = -2 \tag{28}$$

$$a_{30} = -(B_1 \nu_5^2 \nu_6 + B_2 \nu_5 \nu_6 + 2B_4 \nu_6^2 + \nu_6 - \frac{2}{n_f}) \tag{29}$$

The linearized forms of equations (8) and (10) will provide the means of computing the temperature and the pressure

$$b_{11} \delta p + b_{12} \delta T = b_{10} \tag{30}$$

$$b_{21} \delta p + b_{22} \delta T = b_{20} \tag{31}$$

with

$$b_{11} = \frac{1}{p_i} - \frac{T}{T_i n_i} \left(\frac{\partial n_f}{\partial p}\right)_T \tag{32}$$

$$b_{12} = \frac{-1}{T_i n_i} \left(n_f + T \left(\frac{\partial n_f}{\partial T}\right)_p\right) \tag{33}$$

$$b_{10} = \frac{p}{p_i} - \frac{T n_f}{T_i n_i} \tag{34}$$

$$b_{21} = n_f e + (H-RT) \left(\frac{\partial n_f}{\partial p}\right)_T \qquad (35)$$

$$b_{22} = n_f (C_{p_1} + d - R) + (H - RT) \left(\frac{\partial n_f}{\partial T}\right)_p \qquad (36)$$

$$b_{20} = n_f (H - RT) - n_i (H_i - RT_i) \qquad (37)$$

where

$$e = \sum_{j=1}^{7} \left(\frac{\partial \nu_j}{\partial p}\right)_T \cdot H_j (T) \qquad (38)$$

$$d = \sum_{j=1}^{7} \left(\frac{\partial \nu_j}{\partial T}\right)_p \cdot H_j (T) \qquad (39)$$

and C_{p_1} is the molar frozen specific heat, i.e.

$$C_{p_1} = \sum_{j=1}^{7} \nu_j C_{pj} \qquad (40)$$

When the composition, the temperature and pressure have been determined, the following quantities are computed:

a) the molecular weight

$$\mu = \sum_{j=1}^{7} \nu_j \mu_j \qquad (41)$$

b) the molar equilibrium specific heat

$$C_p = \mu \left(\frac{\partial h}{\partial T}\right)_p \qquad (42)$$

$$= C_{p_1} + d - \frac{H}{T} \left(\frac{\partial \ln \mu}{\partial \ln T}\right)_p \qquad (43)$$

c) the isentropic exponent

$$\gamma = \left(\frac{\partial p}{\partial \rho}\right)_s \frac{\mu}{R_0 T} \qquad (44)$$

$$= \left(\frac{\partial \ln p}{\partial \ln \rho}\right)_s \qquad (45)$$

$$= \left(\left(1 + \left(\frac{\partial \ln \mu}{\partial \ln p}\right)_T - \frac{R}{C_p} \left(1 - \left(\frac{\partial \ln \mu}{\partial \ln T}\right)_p\right)^2 \right)^{-1} \qquad (46)$$

d) the equilibrium specific heat ratio

$$\gamma^* = \frac{C_p}{C_v} \tag{47}$$

$$= \gamma \left(1 + \left(\frac{\partial \ln \mu}{\partial \ln p}\right)_T \right) \tag{48}$$

e) the frozen specific heat ratio

$$\gamma_1 = \frac{C_{p_1}}{C_{v_1}} \tag{49}$$

$$= \frac{C_{p_1}}{C_{p_1} - R} \tag{50}$$

f) the frozen speed of sound (a_1), the equilibrium speed of sound (a) and a fictitious speed of sound computed using the equilibrium specific heat ratio instead of the isentropic exponent.

$$a_1 = R_o^{1/2} \left(\frac{\gamma_1 T}{\mu}\right)^{1/2} \tag{51}$$

$$a = R_o^{1/2} \left(\frac{\gamma T}{\mu}\right)^{1/2} \tag{52}$$

$$a^* = R_o^{1/2} \left(\frac{\gamma^* T}{\mu}\right)^{1/2} \tag{53}$$

where R_o is the universal gas constant for which the value 8314 $m^2 sec^{-2}$ $^oK^{-1} gr.$ has been used.

4. RESULTS

Computations have been performe d for the initial conditions

T_i = 298. 15 ^oK

p_i = 1. ; 5. ; 10. ; 30. ; 50. ; 100. ; 300. ; 500. atm.

and the dilutions

1) m=0 and n varying from 0 to 12 in steps of 0. 5
2) n=0 and m varying from 0 to 7. 5 in steps of 0. 5

The results are given Tables 1. and 2. and some are presented graphically in Figures 1. to 6. Incidentally, the intermediate results, p, T, n_f/n_i, C_{p_1}, H_2O, OH, ..., constitutes a verification of the data tabulated in Ref. 1 (*). A comparison is illustrated for the case T_i = 298. 15 ^oK, p_i = 1 atm., m = n = 0. The agreement is excellent.

Quantity	This report	UTIAS T. N. NO. 85
p/p_i	9. 611	9. 611
T/T_i	11. 750	11. 750
n_f/n_i	0. 818	0. 818
μ	14. 684	14. 684
γ_1	1. 214	1. 214
C_{p_1}	11. 282	11. 282
ν_{H_2O}	0. 5560	0. 5560
ν_{OH}	0. 1268	0. 1268
ν_{H_2}	0. 1577	0. 1577
ν_{O_2}	0. 0486	0. 0486
ν_H	0. 0758	0. 0758
ν_O	0. 0351	0. 0351

The effect of temperature on the composition (characterized by the partial derivatives of the molar fractions with respect to temperature) leads to values of the equilibrium specific heat (C_p) appreciably higher than the values obtained neglecting the variations of the composition (C_{p_1}). The difference between C_p and C_{p_1}

$$C_p - C_{p_1} = \sum_{j=1}^{7} \left(\frac{\partial \nu_j}{\partial T}\right)_p H_j(T) - \frac{H}{T}\left(\frac{\partial \ln \mu}{\partial \ln T}\right)_p$$

(*) Note - In Ref. 1., The value used for R_0 was slightly larger than the accepted value, consequently all the values of a_f and a_i should be multiplied by the factor 0. 9902 to obtain the correct values.

increases with decreasing initial pressure and decreases with increasing dilution. The initial pressure has a much stronger influence on C_p than on C_{p_1}. For m = n = 0, C_p is approximately five times as large as C_{p_1} for p_i = 1 atm, and about three times for p_i = 100 atm., while the variation of C_{p_1} remains of the order of 12% (see Fig. 1 and 2).

The difference between the isentropic exponent (γ) and the equilibrium specific ratio (γ*) is as large as 10% for a stoichiometric mixture of hydrogen-oxygen and an initial pressure of one atmosphere. This difference decreases rapidly with increasing dilution. Although the difference between C_p and C_{p_1} is found to be a maximum for the stoichiometric mixture, the values of the specific heat ratios γ^* and γ_1 are rather close in the neighborhood of m = n = 0. In fact the difference $|\gamma^* - \gamma_1|$ reaches a maximum for a value of the dilution index depending on the type of diluting gas and on the initial pressure. For instance, for hydrogen dilution and p_i = 100 atm., this maximum is close to m = 2. The isentropic exponent and the specific heat ratios are presented graphically in Fig. 3 and 4 for helium and hydrogen dilutions respectively.

The various expressions for the speed of sound are represented in Fig. 5 for helium dilution and in Fig. 6 for hydrogen dilution. According to the definitions (51), (52) and (53), what has been said for the γ's can be repeated for the sound speeds, (see Fig. 5 and 6).

5. CONCLUSIONS

The equilibrium specific heat ratio and the isentropic exponent have been computed for reaching gas mixtures composed of stoichiometric hydrogen-oxygen diluted with helium or hydrogen. The values of these quantities have been compared with the frozen specific heat ratio for initial pressures ranging from 1 to 500 atm. and diluting index ranging from 1 to 7.5 in the case of hydrogen dilution, and from 1 to 12 in the case of helium dilution. In each calculation the initial temperature was chosen equal to 298.15°K, but the computer program does not include any such restriction.

Differences of the order of ten percent, were found between the isentropic exponent and the equilibrium specific heat ratio for initial pressure as high as one atmosphere. In both cases of helium and hydrogen dilutions, this difference was a maximum for the stoichiometric hydrogen-oxygen mixture.

The difference between the equilibrium and frozen specific heat ratios, was a maximum for a dilution depending on the diluting gas and the initial pressure.

In the case of helium dilution, and p_i = 1. atm, this difference reaches about 15% for a dilution index n of the order of 5. 5 (approximately 65% of helium per volume in the initial mixture). The different values of the speed of sound evaluated using the isentropic exponent, the equilibrium and frozen specific heat ratios have also been computed and compared.

REFERENCES

1.	Benoit, A.	Thermodynamic and Composition Data for Constant-Volume Combustion of Stoichiometric Mixtures of Hydrogen-Oxygen Diluted with Helium or Hydrogen. UTIAS Technical Note No. 85, November, 1964
2.	McBride, B. J. Heimel, S. Ehlers, J. G.	Thermodynamic Properties to 6000°K for 210 Substances Involving the 18 Elements. NASA SP-3001, July, 1963.

LIST OF TABLES

SYMBOLS USED IN TABLES 1 AND 2

Tables 1 and 2 are the direct outputs of the computer. The following symbols have been used:

PI	: p_i (atm)
TI	: T_i (^oK)
N	: n
M	: m
CP1	: C_{p_1} (cal mole^{-1})
CP	: C_p (cal mole^{-1})
GAMI	: γ_1
GAM*	: γ^*
GAM	: γ
A1	: a_1 (m sec^{-1})
A*	: a^* (m sec^{-1})
A	: a (m sec^{-1})

PI= 1.000

TABLE 1 - PAGE 1

TI= 298.15 M= 0.

N	P/PI	T/TI	CPI	CP	GAMI	GAM*	GAM	AI	A*	A
0.	9.611	11.750	11.282	58.941	1.214	1.212	1.124	1551.7	1550.6	1493.2
0.5	9.641	11.531	10.280	48.795	1.240	1.200	1.131	1651.2	1624.3	1577.0
1.0	9.629	11.329	9.556	41.473	1.263	1.193	1.137	1735.3	1686.4	1646.9
1.5	9.590	11.141	9.008	35.929	1.283	1.189	1.144	1807.0	1739.5	1706.2
2.0	9.533	10.962	8.578	31.559	1.301	1.188	1.151	1868.7	1785.4	1757.0
2.5	9.463	10.791	8.232	28.031	1.318	1.189	1.158	1922.1	1825.5	1801.2
3.0	9.385	10.626	7.947	25.115	1.333	1.191	1.165	1968.4	1860.7	1839.9
3.5	9.301	10.466	7.707	22.663	1.347	1.195	1.173	2008.8	1892.0	1874.1
4.0	9.211	10.309	7.503	20.578	1.360	1.200	1.181	2043.9	1920.0	1904.6
4.5	9.117	10.155	7.327	18.781	1.372	1.206	1.190	2074.5	1945.1	1931.9
5.0	9.019	10.005	7.173	17.221	1.383	1.213	1.199	2101.1	1967.9	1956.5
5.5	8.919	9.853	7.037	15.857	1.394	1.221	1.209	2124.0	1988.5	1978.8
6.0	8.816	9.704	6.916	14.658	1.403	1.230	1.220	2143.8	2007.4	1999.0
6.5	8.710	9.556	6.808	13.598	1.412	1.240	1.231	2160.7	2024.8	2017.6
7.0	8.602	9.408	6.710	12.661	1.421	1.251	1.243	2174.9	2040.7	2034.6
7.5	8.493	9.261	6.620	11.829	1.429	1.262	1.256	2186.8	2055.4	2050.2
8.0	8.381	9.115	6.539	11.088	1.437	1.275	1.269	2196.4	2068.9	2064.5
8.5	8.268	8.969	6.464	10.431	1.444	1.288	1.283	2204.1	2081.3	2077.6
9.0	8.154	8.823	6.395	9.846	1.451	1.301	1.297	2209.9	2092.7	2089.5
9.5	8.038	8.677	6.331	9.326	1.457	1.315	1.312	2214.0	2103.0	2100.4
10.0	7.922	8.533	6.272	8.865	1.464	1.329	1.327	2216.6	2112.3	2110.1
10.5	7.805	8.389	6.216	8.457	1.470	1.344	1.342	2217.7	2120.6	2118.7
11.0	7.688	8.246	6.164	8.096	1.476	1.358	1.356	2217.6	2127.7	2126.1
11.5	7.571	8.104	6.116	7.776	1.481	1.373	1.371	2216.3	2133.8	2132.5
12.0	7.454	7.964	6.070	7.495	1.487	1.387	1.386	2214.0	2138.8	2137.7

TABLE 1 - PAGE 2

PI= 5.000

TI= 298.15 M= 0.

N	P/PI	T/TI	CPI	CP	GAMI	GAM*	GAM	AI	A*	A
0.	10.146	12.713	11.688	47.355	1.205	1.209	1.132	1588.4	1590.9	1539.9
0.5	10.188	12.436	10.594	39.268	1.231	1.200	1.141	1691.3	1669.9	1628.3
1.0	10.174	12.181	9.809	33.452	1.254	1.196	1.149	1777.6	1735.9	1701.5
1.5	10.125	11.942	9.218	29.048	1.275	1.195	1.157	1850.8	1791.9	1763.2
2.0	10.053	11.716	8.756	25.583	1.294	1.197	1.165	1913.2	1840.0	1816.0
2.5	9.966	11.499	8.384	22.787	1.311	1.200	1.174	1966.8	1881.8	1861.5
3.0	9.867	11.289	8.078	20.482	1.326	1.205	1.183	2012.9	1918.4	1901.2
3.5	9.760	11.086	7.822	18.548	1.341	1.211	1.193	2052.6	1950.7	1936.1
4.0	9.647	10.887	7.604	16.907	1.354	1.218	1.203	2086.8	1979.3	1966.9
4.5	9.528	10.693	7.416	15.496	1.366	1.226	1.213	2116.1	2004.9	1994.4
5.0	9.406	10.502	7.251	14.278	1.377	1.236	1.225	2141.2	2027.8	2019.0
5.5	9.280	10.313	7.106	13.217	1.388	1.246	1.237	2162.5	2048.5	2041.0
6.0	9.151	10.127	6.977	12.289	1.398	1.257	1.249	2180.4	2067.2	2060.8
6.5	9.020	9.944	6.862	11.475	1.408	1.269	1.262	2195.2	2084.0	2078.7
7.0	8.888	9.762	6.758	10.759	1.417	1.281	1.276	2207.4	2099.2	2094.7
7.5	8.753	9.582	6.663	10.128	1.425	1.294	1.290	2217.1	2112.9	2109.2
8.0	8.618	9.404	6.576	9.571	1.433	1.308	1.304	2224.5	2125.2	2122.0
8.5	8.482	9.227	6.497	9.080	1.441	1.322	1.319	2229.9	2136.0	2133.4
9.0	8.346	9.053	6.423	8.648	1.448	1.336	1.333	2233.5	2145.5	2143.4
9.5	8.209	8.882	6.356	8.267	1.455	1.350	1.348	2235.4	2153.7	2151.9
10.0	8.073	8.713	6.293	7.932	1.462	1.365	1.363	2235.9	2160.6	2159.1
10.5	7.938	8.546	6.235	7.638	1.468	1.379	1.377	2235.1	2166.2	2164.9
11.0	7.804	8.383	6.180	7.379	1.474	1.392	1.391	2233.0	2170.4	2169.4
11.5	7.672	8.222	6.129	7.152	1.480	1.406	1.405	2229.9	2173.5	2172.6
12.0	7.541	8.066	6.081	6.953	1.485	1.419	1.418	2225.9	2175.4	2174.7

TABLE 1 - PAGE 3

PI= 10.000

TI= 298.15 M= 0.

N	P/PI	T/TI	CPI	CP	GAMI	GAM*	GAM	AI	A*	A
0.	10.375	13.149	11.877	43.064	1.201	1.207	1.136	1603.6	1607.6	1559.6
0.5	10.423	12.843	10.738	35.752	1.227	1.200	1.145	1708.1	1689.0	1650.1
1.0	10.408	12.560	9.923	30.496	1.250	1.197	1.154	1795.4	1756.8	1724.9
1.5	10.354	12.296	9.311	26.523	1.271	1.198	1.163	1869.1	1814.2	1787.7
2.0	10.275	12.044	8.833	23.400	1.290	1.201	1.172	1931.7	1863.4	1841.2
2.5	10.179	11.804	8.450	20.879	1.307	1.205	1.182	1985.3	1905.9	1887.3
3.0	10.070	11.572	8.135	18.805	1.323	1.211	1.191	2031.1	1942.9	1927.3
3.5	9.951	11.347	7.871	17.066	1.338	1.218	1.202	2070.4	1975.6	1962.4
4.0	9.826	11.128	7.646	15.593	1.351	1.226	1.213	2104.0	2004.4	1993.3
4.5	9.696	10.914	7.452	14.329	1.364	1.236	1.224	2132.7	2030.1	2020.8
5.0	9.561	10.704	7.283	13.239	1.375	1.246	1.236	2157.0	2053.0	2045.1
5.5	9.423	10.497	7.134	12.292	1.386	1.257	1.249	2177.4	2073.4	2066.8
6.0	9.282	10.294	7.002	11.467	1.396	1.269	1.262	2194.4	2091.8	2086.3
6.5	9.140	10.094	6.883	10.744	1.406	1.281	1.276	2208.4	2108.2	2103.6
7.0	8.996	9.896	6.776	10.110	1.415	1.294	1.290	2219.5	2122.8	2119.0
7.5	8.850	9.702	6.678	9.554	1.424	1.308	1.304	2228.2	2135.8	2132.6
8.0	8.705	9.510	6.590	9.064	1.432	1.322	1.319	2234.7	2147.2	2144.6
8.5	8.559	9.321	6.508	8.634	1.440	1.336	1.333	2239.1	2157.2	2155.0
9.0	8.414	9.135	6.433	8.257	1.447	1.350	1.348	2241.8	2165.6	2163.8
9.5	8.269	8.953	6.364	7.926	1.454	1.364	1.362	2242.9	2172.6	2171.1
10.0	8.125	8.774	6.300	7.634	1.461	1.378	1.377	2242.5	2178.3	2177.0
10.5	7.983	8.599	6.241	7.378	1.467	1.392	1.390	2240.9	2182.5	2181.5
11.0	7.843	8.438	6.185	7.154	1.473	1.405	1.404	2238.1	2185.5	2184.7
11.5	7.705	8.261	6.133	6.958	1.479	1.418	1.417	2234.4	2187.3	2186.6
12.0	7.570	8.099	6.085	6.786	1.485	1.430	1.429	2229.8	2187.8	2187.2

PI= 30.000

TI= 298.15 M= 0.

TABLE 1 - PAGE 4

N	P/PI	T/TI	CPI	CP	GAMI	GAM*	GAM	AI	A*	A
0.	10.731	13.858	12.193	37.098	1.195	1.204	1.141	1626.7	1632.7	1589.7
0.5	10.789	13.499	10.975	30.871	1.221	1.200	1.152	1733.6	1718.3	1683.8
1.0	10.772	13.167	10.108	26.405	1.245	1.200	1.162	1822.4	1789.1	1761.1
1.5	10.710	12.856	9.460	23.033	1.266	1.202	1.173	1896.8	1848.7	1825.6
2.0	10.617	12.561	8.956	20.392	1.285	1.207	1.183	1959.7	1899.4	1880.3
2.5	10.504	12.279	8.552	18.263	1.303	1.214	1.194	2013.0	1943.1	1927.2
3.0	10.377	12.008	8.221	16.513	1.319	1.221	1.205	2058.4	1980.9	1967.7
3.5	10.239	11.746	7.944	15.051	1.334	1.230	1.217	2096.8	2013.9	2003.0
4.0	10.094	11.492	7.709	13.814	1.347	1.240	1.229	2129.4	2042.9	2033.8
4.5	9.943	11.244	7.506	12.758	1.360	1.251	1.242	2156.8	2068.5	2060.9
5.0	9.788	11.002	7.330	11.850	1.372	1.262	1.255	2179.8	2091.0	2084.7
5.5	9.630	10.765	7.174	11.064	1.383	1.275	1.268	2198.8	2110.9	2105.7
6.0	9.470	10.534	7.036	10.381	1.394	1.288	1.282	2214.3	2128.5	2124.2
6.5	9.308	10.307	6.912	9.786	1.403	1.301	1.297	2226.7	2144.0	2140.4
7.0	9.146	10.085	6.801	9.267	1.413	1.315	1.311	2236.3	2157.4	2154.4
7.5	8.984	9.868	6.700	8.813	1.422	1.329	1.326	2243.5	2168.9	2166.5
8.0	8.823	9.655	6.608	8.416	1.430	1.343	1.340	2248.4	2178.8	2176.8
8.5	8.663	9.447	6.524	8.068	1.438	1.357	1.355	2251.5	2186.9	2185.3
9.0	8.504	9.245	6.447	7.764	1.446	1.370	1.369	2252.8	2193.4	2192.1
9.5	8.347	9.047	6.376	7.497	1.453	1.384	1.383	2252.5	2198.5	2197.4
10.0	8.193	8.855	6.310	7.263	1.460	1.397	1.396	2251.0	2202.2	2201.3
10.5	8.041	8.668	6.249	7.059	1.466	1.410	1.409	2248.3	2204.4	2203.6
11.0	7.892	8.486	6.192	6.879	1.473	1.422	1.421	2244.6	2205.4	2204.8
11.5	7.747	8.310	6.139	6.722	1.479	1.433	1.432	2240.0	2205.1	2204.6
12.0	7.605	8.140	6.089	6.584	1.484	1.444	1.443	2234.6	2203.8	2203.4

TABLE 1 - PAGE 5

PI= 50.000

TI= 298.15 M= 0.

N	P/PI	T/TI	CPI	CP	GAMI	GAM*	GAM	AI	A*	A
0.	10.891	14.192	12.345	34.655	1.192	1.202	1.143	1636.8	1643.5	1603.1
0.5	10.954	13.805	11.087	28.876	1.218	1.199	1.155	1744.9	1731.2	1698.9
1.0	10.937	13.448	10.195	24.739	1.242	1.201	1.166	1834.5	1803.5	1777.3
1.5	10.870	13.113	9.529	21.616	1.263	1.205	1.177	1909.1	1864.2	1842.7
2.0	10.770	12.796	9.012	19.172	1.283	1.211	1.188	1972.0	1915.6	1898.0
2.5	10.649	12.493	8.509	17.207	1.301	1.218	1.200	2025.2	1959.7	1945.2
3.0	10.512	12.203	8.260	15.592	1.317	1.226	1.212	2070.2	1997.9	1985.8
3.5	10.365	11.922	7.977	14.245	1.332	1.236	1.224	2108.2	2031.0	2021.1
4.0	10.209	11.650	7.737	13.106	1.346	1.247	1.237	2140.3	2060.0	2051.8
4.5	10.049	11.386	7.530	12.136	1.359	1.258	1.250	2167.1	2085.5	2078.6
5.0	9.884	11.129	7.349	11.304	1.371	1.270	1.263	2189.4	2107.7	2102.1
5.5	9.717	10.878	7.191	10.583	1.382	1.283	1.277	2207.7	2127.3	2122.6
6.0	9.547	10.634	7.050	9.959	1.392	1.296	1.292	2222.5	2144.4	2140.5
6.5	9.378	10.395	6.925	9.417	1.402	1.310	1.306	2234.2	2159.2	2156.0
7.0	9.208	10.162	6.811	8.944	1.412	1.324	1.321	2243.1	2172.0	2169.4
7.5	9.038	9.934	6.709	8.531	1.421	1.338	1.335	2249.6	2182.8	2180.6
8.0	8.870	9.713	6.615	8.171	1.429	1.352	1.350	2253.9	2191.8	2190.1
8.5	8.703	9.497	6.530	7.855	1.437	1.365	1.364	2256.3	2199.0	2197.6
9.0	8.539	9.287	6.452	7.580	1.445	1.379	1.377	2257.0	2204.7	2203.6
9.5	8.377	9.083	6.380	7.338	1.452	1.392	1.391	2256.3	2208.9	2207.9
10.0	8.218	8.885	6.313	7.127	1.459	1.405	1.404	2254.2	2211.6	2210.8
10.5	8.063	8.694	6.251	6.941	1.466	1.417	1.416	2251.1	2212.9	2212.3
11.0	7.911	8.508	6.194	6.779	1.472	1.428	1.427	2247.0	2213.0	2212.5
11.5	7.763	8.328	6.141	6.636	1.478	1.439	1.438	2242.0	2212.0	2211.5
12.0	7.618	8.155	6.091	6.510	1.484	1.449	1.449	2236.4	2209.9	2209.5

TABLE 1 - PAGE 6

PI= 100.000

TI= 298.15 M= 0.

N	P/PI	T/TI	CPI	CP	GAMI	GAM*	GAM	AI	A*	A
0.	11.100	14.645	12.557	31.669	1.188	1.199	1.146	1649.8	1657.4	1620.4
0.5	11.171	14.218	11.241	26.438	1.215	1.199	1.159	1759.4	1748.0	1718.6
1.0	11.152	13.823	10.313	22.701	1.239	1.202	1.171	1849.7	1822.3	1798.6
1.5	11.079	13.454	9.622	19.890	1.260	1.208	1.183	1924.9	1884.4	1865.1
2.0	10.969	13.106	9.087	17.694	1.280	1.215	1.195	1987.8	1936.8	1921.1
2.5	10.836	12.774	8.660	15.928	1.298	1.224	1.208	2040.8	1981.5	1968.7
3.0	10.686	12.455	8.310	14.481	1.314	1.233	1.220	2085.3	2020.0	2009.4
3.5	10.526	12.149	8.019	13.275	1.329	1.244	1.233	2122.7	2053.3	2044.6
4.0	10.357	11.853	7.772	12.259	1.344	1.256	1.247	2154.0	2082.2	2075.0
4.5	10.182	11.567	7.559	11.394	1.357	1.268	1.261	2179.9	2107.3	2101.4
5.0	10.004	11.289	7.374	10.653	1.369	1.281	1.275	2201.3	2129.2	2124.3
5.5	9.824	11.019	7.212	10.015	1.380	1.294	1.289	2218.7	2148.1	2144.1
6.0	9.643	10.757	7.068	9.462	1.391	1.308	1.304	2232.5	2164.4	2161.2
6.5	9.462	10.502	6.939	8.983	1.401	1.321	1.318	2243.2	2178.4	2175.7
7.0	9.282	10.255	6.824	8.567	1.411	1.335	1.333	2251.2	2190.1	2188.0
7.5	9.103	10.015	6.719	8.204	1.420	1.349	1.347	2256.8	2199.9	2198.1
8.0	8.926	9.782	6.624	7.887	1.429	1.363	1.361	2260.3	2207.7	2206.3
8.5	8.751	9.556	6.537	7.610	1.437	1.376	1.375	2262.0	2213.8	2212.7
9.0	8.580	9.337	6.458	7.369	1.444	1.389	1.388	2262.0	2218.3	2217.3
9.5	8.412	9.125	6.385	7.157	1.452	1.402	1.401	2260.6	2221.2	2220.4
10.0	8.248	8.921	6.317	6.971	1.459	1.414	1.413	2258.0	2222.7	2222.1
10.5	8.088	8.723	6.255	6.808	1.466	1.425	1.424	2254.3	2222.9	2222.4
11.0	7.932	8.533	6.197	6.665	1.472	1.436	1.435	2249.7	2221.9	2221.5
11.5	7.780	8.349	6.143	6.539	1.478	1.446	1.446	2244.4	2219.9	2219.5
12.0	7.6[illegible]	8.172	6.093	6.428	1.484	1.456	1.455	2238.4	2216.9	2216.6

TABLE 1 - PAGE 7

PI= 300.000

TI= 298.15 M= 0.

N	P/PI	T/TI	CP1	CP	GAM1	GAM*	GAM	A1	A*	A
0.	11.407	15.349	12.897	27.654	1.182	1.194	1.150	1668.3	1676.8	1645.4
0.5	11.492	14.853	11.485	23.164	1.209	1.198	1.165	1780.5	1772.2	1747.5
1.0	11.471	14.396	10.496	19.977	1.234	1.204	1.179	1872.1	1849.8	1830.1
1.5	11.386	13.969	9.764	17.587	1.256	1.212	1.192	1947.8	1914.1	1898.3
2.0	11.261	13.568	9.199	15.725	1.276	1.222	1.206	2010.6	1968.0	1955.2
2.5	11.108	13.187	8.750	14.235	1.294	1.233	1.220	2063.0	2013.6	2003.2
3.0	10.937	12.823	8.384	13.016	1.311	1.244	1.234	2106.7	2052.5	2044.1
3.5	10.755	12.475	8.080	12.005	1.326	1.256	1.248	2143.0	2085.8	2078.9
4.0	10.564	12.141	7.822	11.154	1.341	1.269	1.262	2173.0	2114.3	2108.7
4.5	10.368	11.820	7.601	10.433	1.354	1.282	1.277	2197.6	2138.8	2134.3
5.0	10.170	11.510	7.409	9.818	1.367	1.296	1.292	2217.6	2159.7	2156.0
5.5	9.971	11.212	7.241	9.288	1.378	1.310	1.306	2233.5	2177.5	2174.5
6.0	9.772	10.924	7.092	8.832	1.389	1.324	1.321	2245.9	2192.4	2190.0
6.5	9.574	10.646	6.959	8.437	1.400	1.338	1.335	2255.2	2204.9	2202.9
7.0	9.379	10.378	6.840	8.094	1.409	1.352	1.350	2261.9	2215.0	2213.4
7.5	9.187	10.119	6.733	7.796	1.419	1.365	1.363	2266.3	2223.0	2221.7
8.0	8.998	9.870	6.635	7.536	1.428	1.378	1.377	2268.6	2229.0	2227.9
8.5	8.813	9.631	6.547	7.309	1.436	1.391	1.390	2269.2	2233.2	2232.4
9.0	8.632	9.400	6.466	7.110	1.444	1.403	1.402	2268.2	2235.9	2235.2
9.5	8.456	9.178	6.391	6.936	1.451	1.414	1.414	2266.0	2237.0	2236.5
10.0	8.285	8.965	6.323	6.783	1.458	1.425	1.425	2262.6	2236.9	2236.5
10.5	8.119	8.760	6.259	6.648	1.465	1.436	1.435	2258.3	2235.5	2235.2
11.0	7.958	8.564	6.200	6.529	1.472	1.446	1.445	2253.1	2233.1	2232.8
11.5	7.802	8.375	6.146	6.423	1.478	1.455	1.454	2247.3	2229.7	2229.4
12.0	7.651	8.194	6.095	6.329	1.484	1.463	1.463	2240.8	2225.4	2225.2

TABLE 1 - PAGE 8

PI= 500.000

TI= 298.15 M= 0.

N	P/PI	T/TI	CP1	CP	GAM1	GAM*	GAM	A1	A*	A
0.	11.538	15.664	13.055	26.063	1.180	1.192	1.151	1676.0	1684.7	1655.8
0.5	11.630	15.135	11.596	21.874	1.207	1.197	1.167	1789.3	1782.3	1759.7
1.0	11.608	14.648	10.578	18.904	1.231	1.205	1.182	1881.5	1861.5	1843.5
1.5	11.518	14.194	9.827	16.682	1.253	1.215	1.197	1957.4	1926.8	1912.4
2.0	11.384	13.767	9.249	14.955	1.274	1.225	1.211	2020.2	1981.4	1969.8
2.5	11.223	13.363	8.789	13.575	1.292	1.237	1.225	2072.3	2027.4	2018.0
3.0	11.042	12.979	8.416	12.447	1.309	1.249	1.240	2115.6	2066.4	2058.8
3.5	10.849	12.612	8.105	11.514	1.325	1.262	1.254	2151.3	2099.6	2093.4
4.0	10.649	12.260	7.843	10.729	1.339	1.275	1.269	2180.8	2127.9	2122.9
4.5	10.444	11.923	7.618	10.066	1.353	1.289	1.284	2204.7	2151.9	2147.9
5.0	10.237	11.600	7.423	9.500	1.366	1.303	1.299	2224.1	2172.4	2169.1
5.5	10.029	11.288	7.252	9.014	1.377	1.317	1.314	2239.4	2189.5	2186.9
6.0	9.823	10.989	7.101	8.595	1.389	1.331	1.328	2251.1	2203.8	2201.7
6.5	9.618	10.702	6.967	8.233	1.399	1.345	1.343	2259.9	2215.5	2213.7
7.0	9.417	10.425	6.847	7.919	1.409	1.358	1.356	2266.0	2224.8	2223.4
7.5	9.219	10.159	6.738	7.646	1.418	1.371	1.370	2269.8	2232.0	2230.9
8.0	9.025	9.904	6.640	7.408	1.427	1.384	1.383	2271.7	2237.2	2236.3
8.5	8.836	9.659	6.550	7.199	1.435	1.396	1.395	2271.9	2240.7	2240.0
9.0	8.652	9.424	6.468	7.017	1.443	1.408	1.407	2270.5	2242.6	2242.0
9.5	8.472	9.198	6.393	6.856	1.451	1.419	1.419	2268.0	2243.0	2242.5
10.0	8.299	8.981	6.324	6.715	1.458	1.430	1.429	2264.3	2242.2	2241.8
10.5	8.130	8.774	6.261	6.590	1.465	1.440	1.439	2259.7	2240.2	2239.9
11.0	7.967	8.575	6.202	6.480	1.472	1.449	1.449	2254.3	2237.2	2237.0
11.5	7.810	8.384	6.147	6.382	1.478	1.458	1.458	2248.3	2233.3	2233.1
12.0	7.658	8.201	6.096	6.294	1.484	1.466	1.466	2241.7	2228.6	2228.5

TABLE 2 - Page 1

PI= 1.000

TI= 298.15 N= 0.

M	P/PI	T/TI	CPI	CP	GAMI	GAM*	GAM	AI	A*	A
0.	9.611	11.750	11.282	58.941	1.214	1.212	1.124	1551.7	1550.6	1493.2
0.5	9.614	11.687	11.192	54.295	1.216	1.205	1.126	1654.8	1647.6	1592.4
1.0	9.523	11.483	11.062	44.757	1.219	1.191	1.130	1739.4	1719.2	1674.8
1.5	9.369	11.199	10.912	35.956	1.223	1.180	1.136	1808.8	1777.2	1743.9
2.0	9.176	10.874	10.755	29.363	1.227	1.176	1.144	1866.1	1827.0	1802.2
2.5	8.963	10.533	10.597	24.585	1.231	1.176	1.153	1913.6	1870.3	1851.9
3.0	8.740	10.190	10.447	21.052	1.235	1.179	1.162	1953.3	1908.3	1894.6
3.5	8.512	9.851	10.290	18.364	1.239	1.184	1.172	1986.2	1941.7	1931.6
4.0	8.284	9.520	10.143	16.276	1.244	1.192	1.183	2013.6	1971.1	1963.7
4.5	8.057	9.197	10.000	14.636	1.248	1.200	1.194	2035.9	1996.8	1991.4
5.0	7.833	8.884	9.862	13.341	1.252	1.210	1.205	2054.1	2019.1	2015.3
5.5	7.613	8.582	9.728	12.319	1.257	1.220	1.217	2068.5	2038.2	2035.5
6.0	7.399	8.292	9.600	11.514	1.261	1.230	1.228	2079.7	2054.2	2052.3
6.5	7.191	8.016	9.477	10.882	1.265	1.240	1.238	2088.3	2067.3	2065.9
7.0	6.990	7.753	9.361	10.386	1.270	1.249	1.248	2094.6	2077.7	2076.7
7.5	6.798	7.504	9.250	9.995	1.274	1.257	1.257	2099.0	2065.6	2084.9

PI= 5.000

TI= 298.15 N= 0.

M	P/PI	T/TI	CPI	CP	GAMI	GAM*	GAM	AI	A*	A
0.	10.146	12.713	11.688	47.354	1.205	1.209	1.132	1588.4	1590.9	1539.9
0.5	10.141	12.620	11.584	43.018	1.207	1.202	1.135	1693.3	1689.5	1641.9
1.0	10.013	12.329	11.415	34.808	1.211	1.189	1.140	1777.5	1761.1	1725.1
1.5	9.807	11.936	11.219	27.883	1.215	1.181	1.148	1845.1	1819.2	1793.5
2.0	9.560	11.502	11.015	22.964	1.220	1.180	1.158	1899.7	1868.5	1850.4
2.5	9.293	11.059	10.815	19.495	1.225	1.184	1.168	1944.1	1910.9	1898.1
3.0	9.018	10.622	10.620	16.976	1.230	1.190	1.179	1980.2	1947.3	1938.2
3.5	8.742	10.199	10.434	15.097	1.235	1.197	1.190	2009.6	1978.5	1972.2
4.0	8.470	9.794	10.257	13.671	1.240	1.206	1.201	2033.3	2005.2	2000.7
4.5	8.204	9.409	10.088	12.579	1.245	1.216	1.212	2052.2	2027.7	2024.6
5.0	7.947	9.045	9.929	11.737	1.250	1.225	1.223	2067.1	2046.4	2044.3
5.5	7.699	8.702	9.778	11.086	1.255	1.235	1.233	2078.8	2061.7	2060.3
6.0	7.463	8.380	9.637	10.579	1.260	1.243	1.242	2087.7	2073.9	2072.9
6.5	7.238	8.079	9.504	10.180	1.264	1.251	1.250	2094.3	2083.4	2082.7
7.0	7.024	7.798	9.380	9.864	1.269	1.259	1.258	2099.0	2090.6	2090.1
7.5	6.822	7.536	9.263	9.611	1.273	1.265	1.265	2102.3	2095.8	2095.5

TABLE 2 - Page 2

PI= 10.000

TI= 298.15 N= 0.

M	P/PI	T/TI	CPI	CP	GAMI	GAM*	GAM	AI	A*	A
0.	10.375	13.149	11.877	43.064	1.201	1.207	1.136	1603.6	1607.6	1559.6
0.5	10.364	13.037	11.763	38.825	1.203	1.200	1.139	1709.2	1706.6	1662.7
1.0	10.215	12.695	[illegible]	31.172	1.207	1.188	1.145	1792.8	1773.1	1745.9
1.5	9.983	12.242	11.348	25.013	1.212	1.182	1.154	1859.2	1836.0	1813.7
2.0	9.708	11.751	11.120	20.750	1.218	1.183	1.164	1912.3	1884.8	1869.5
2.5	9.415	11.257	10.897	17.780	1.223	1.187	1.174	1955.1	1926.4	1915.9
3.0	9.116	10.777	10.685	15.645	1.228	1.194	1.186	1989.6	1961.8	1954.5
3.5	8.820	10.318	10.484	14.066	1.234	1.203	1.197	2017.3	1991.8	1986.7
4.0	8.530	9.884	10.294	12.878	1.239	1.212	1.208	2039.5	2016.9	2013.5
4.5	8.249	9.475	10.116	11.976	1.244	1.221	1.218	2057.1	2037.9	2035.5
5.0	7.980	9.092	9.949	11.284	1.250	1.230	1.229	2070.9	2055.0	2053.4
5.5	7.724	8.735	9.793	10.748	1.255	1.239	1.238	2081.6	2068.7	2067.7
6.0	7.480	8.404	9.647	10.330	1.259	1.247	1.246	2089.8	2079.6	2078.9
6.5	7.250	8.095	9.511	9.998	1.264	1.254	1.254	2095.8	2087.9	2087.4
7.0	7.033	7.809	9.384	9.732	1.269	1.261	1.261	2100.2	2094.0	2093.7
7.5	6.828	7.544	9.266	9.515	1.273	1.267	1.267	2103.1	2098.4	2098.1

PI= 30.000

TI= 298.15 N= 0.

M	P/PI	T/TI	CPI	CP	GAMI	GAM*	GAM	AI	A*	A
0.	10.731	13.858	12.193	37.095	1.195	1.204	1.141	1626.7	1632.7	1589.7
0.5	10.707	13.705	12.058	32.969	1.197	1.196	1.145	1732.9	1732.0	1694.2
1.0	10.516	13.259	11.816	26.198	1.202	1.186	1.152	1815.1	1802.9	1777.0
1.5	10.235	12.695	11.541	21.206	1.208	1.184	1.162	1879.2	1860.2	1843.2
2.0	9.913	12.104	11.269	17.886	1.214	1.187	1.173	1929.6	1908.0	1896.8
2.5	9.577	11.527	11.010	15.618	1.220	1.194	1.184	1969.7	1948.0	1940.5
3.0	9.242	10.979	10.769	14.009	1.226	1.202	1.196	2001.5	1981.4	1976.4
3.5	8.916	10.467	10.545	12.832	1.232	1.211	1.207	2026.9	2009.0	2005.7
4.0	8.601	9.991	10.339	11.956	1.238	1.220	1.217	2047.0	2031.8	2029.6
4.5	8.301	9.551	10.147	11.291	1.244	1.228	1.227	2062.8	2050.2	2048.8
5.0	8.018	9.146	9.971	10.780	1.249	1.237	1.236	2075.2	2065.1	2064.1
5.5	7.750	8.773	9.808	10.380	1.254	1.244	1.244	2084.8	2076.8	2076.1
6.0	7.499	8.429	9.658	10.063	1.259	1.252	1.251	2092.1	2085.8	2085.4
6.5	7.263	8.113	9.518	9.806	1.264	1.258	1.258	2097.5	2092.7	2092.4
7.0	7.042	7.821	9.390	9.594	1.268	1.264	1.264	2101.4	2097.7	2097.5
7.5	6.834	7.552	9.270	9.415	1.273	1.269	1.269	2104.0	2101.2	2101.1

PI= 50.000

TI= 298.15 N= 0.

M	P/PI	T/TI	CPI	CP	GAM1	GAM*	GAM	A1	A*	A
0.	10.891	14.192	12.345	34.657	1.192	1.202	1.143	1636.8	1643.5	1603.1
0.5	10.858	14.013	12.197	30.563	1.195	1.194	1.147	1743.1	1742.9	1708.1
1.0	10.644	13.508	11.926	24.218	1.200	1.185	1.155	1824.5	1813.4	1790.4
1.5	10.338	12.886	11.624	19.737	1.206	1.185	1.166	1887.3	1870.4	1855.6
2.0	9.994	12.247	11.330	16.811	1.213	1.189	1.177	1936.4	1917.5	1907.9
2.5	9.640	11.632	11.054	14.827	1.219	1.196	1.189	1975.2	1956.6	1950.3
3.0	9.289	11.055	10.801	13.425	1.225	1.205	1.200	2005.9	1988.9	1984.8
3.5	8.950	10.520	10.568	12.403	1.232	1.214	1.210	2030.3	2015.5	2012.7
4.0	8.626	10.028	10.354	11.641	1.238	1.222	1.220	2049.6	2037.1	2035.3
4.5	8.319	9.577	10.158	11.063	1.243	1.231	1.230	2064.8	2054.6	2053.4
5.0	8.030	9.164	9.978	10.615	1.249	1.239	1.238	2076.6	2068.6	2067.8
5.5	7.759	8.785	9.813	10.262	1.254	1.246	1.246	2085.8	2079.5	2078.9
6.0	7.505	8.438	9.661	9.978	1.259	1.253	1.253	2092.8	2087.9	2087.6
6.5	7.267	8.119	9.521	9.745	1.264	1.259	1.259	2098.1	2094.3	2094.1
7.0	7.045	7.825	9.391	9.550	1.268	1.265	1.265	2101.8	2098.9	2098.7
7.5	6.836	7.555	9.271	9.384	1.273	1.270	1.270	2104.3	2102.1	2102.0

PI= 100.000

TI= 298.15 N= 0.

M	P/PI	T/TI	CPI	CP	GAM1	GAM*	GAM	A1	A*	A
0.	11.100	14.645	12.557	31.669	1.188	1.199	1.146	1649.8	1657.4	1620.4
0.5	11.053	14.422	12.386	27.613	1.191	1.192	1.150	1756.1	1756.5	1725.9
1.0	10.805	13.827	12.070	21.855	1.197	1.185	1.160	1836.0	1826.5	1807.2
1.5	10.464	13.121	11.728	18.034	1.204	1.186	1.171	1897.0	1882.8	1870.8
2.0	10.090	12.417	11.403	15.590	1.211	1.192	1.183	1944.3	1928.9	1921.3
2.5	9.711	11.753	11.105	13.945	1.218	1.200	1.194	1981.5	1966.6	1961.8
3.0	9.341	11.140	10.836	12.786	1.225	1.208	1.205	2010.8	1997.5	1994.4
3.5	8.987	10.579	10.592	11.941	1.231	1.217	1.215	2034.0	2022.7	2020.6
4.0	8.652	10.069	10.371	11.309	1.237	1.226	1.224	2052.3	2043.0	2041.7
4.5	8.338	9.604	10.170	10.824	1.243	1.234	1.233	2066.8	2059.3	2058.4
5.0	8.043	9.182	9.986	10.444	1.248	1.241	1.241	2078.1	2072.2	2071.6
5.5	7.768	8.797	9.819	10.140	1.254	1.248	1.248	2086.9	2082.2	2081.9
6.0	7.511	8.446	9.665	9.890	1.259	1.255	1.254	2093.6	2090.0	2089.8
6.5	7.271	8.124	9.523	9.682	1.264	1.260	1.260	2098.6	2095.9	2095.7
7.0	7.048	7.829	9.393	9.506	1.268	1.266	1.266	2102.2	2100.1	2100.0
7.5	6.838	7.557	9.272	9.352	1.273	1.271	1.271	2104.5	2103.0	2102.9

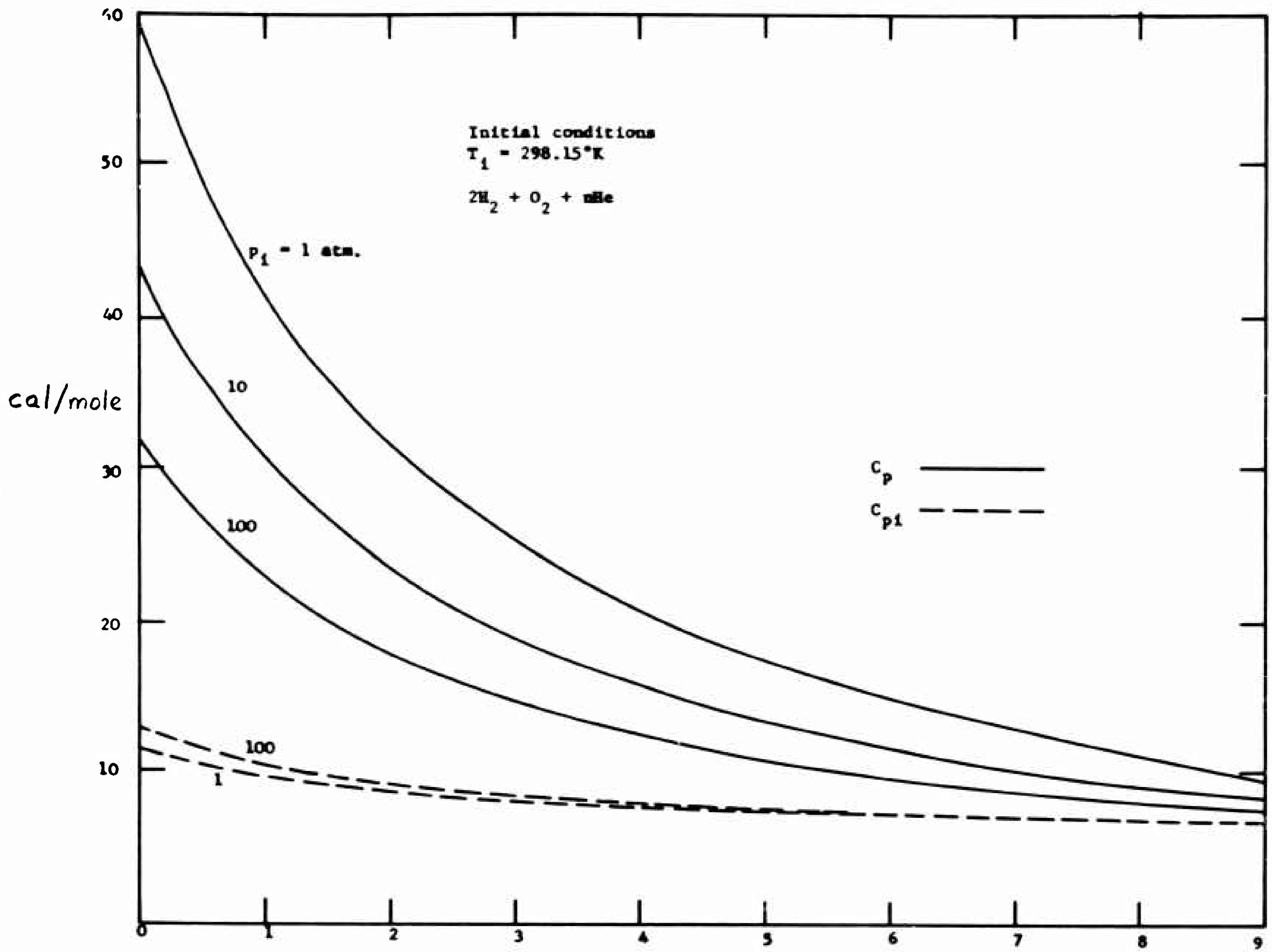

FIG 1 MOLAR SPECIFIC HEAT VERSUS DILUTION (HELIUM DILUTION)

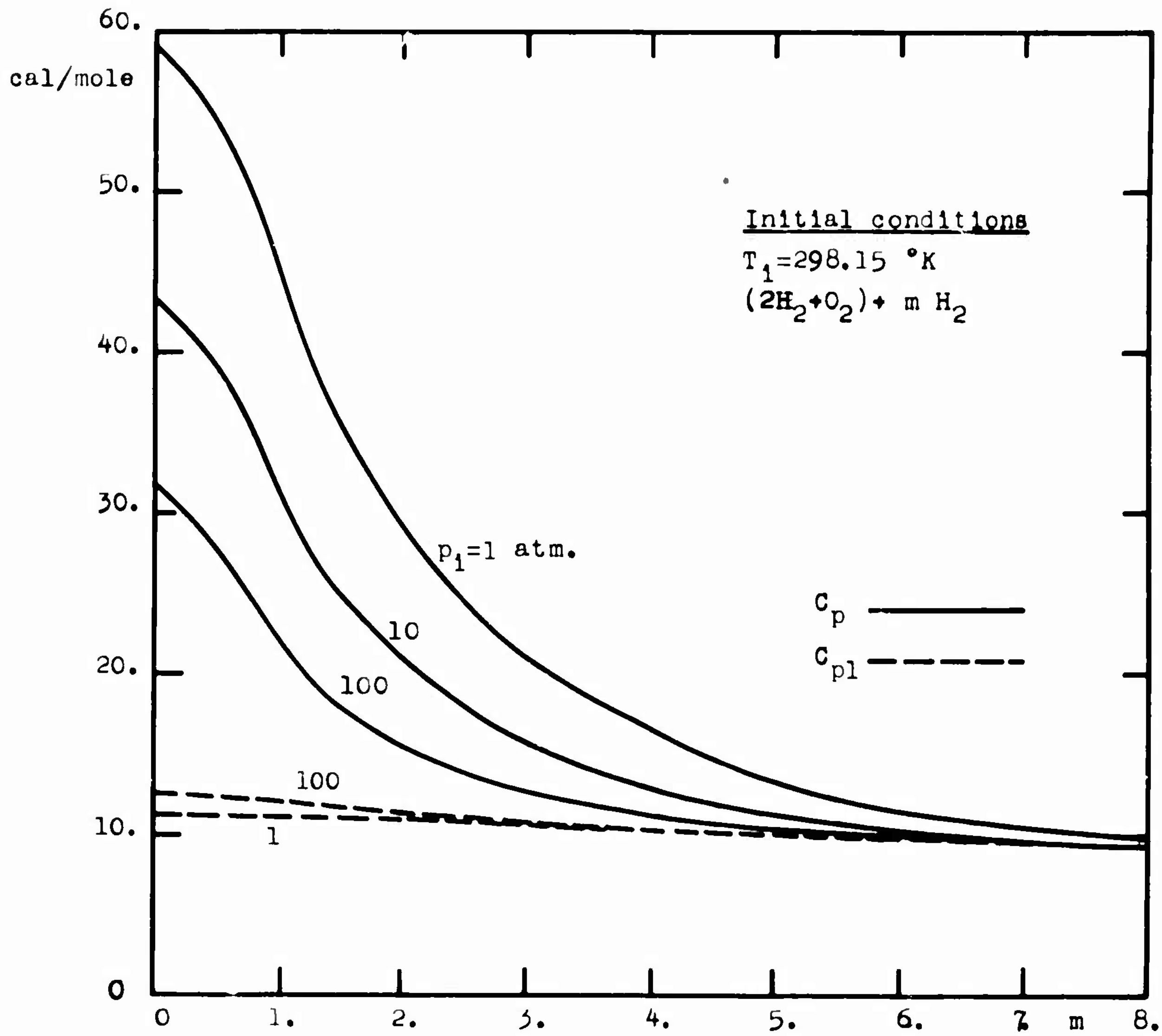

FIG. 2 SPECIFIC HEAT VERSUS DILUTION (HYDROGEN DILUTION)

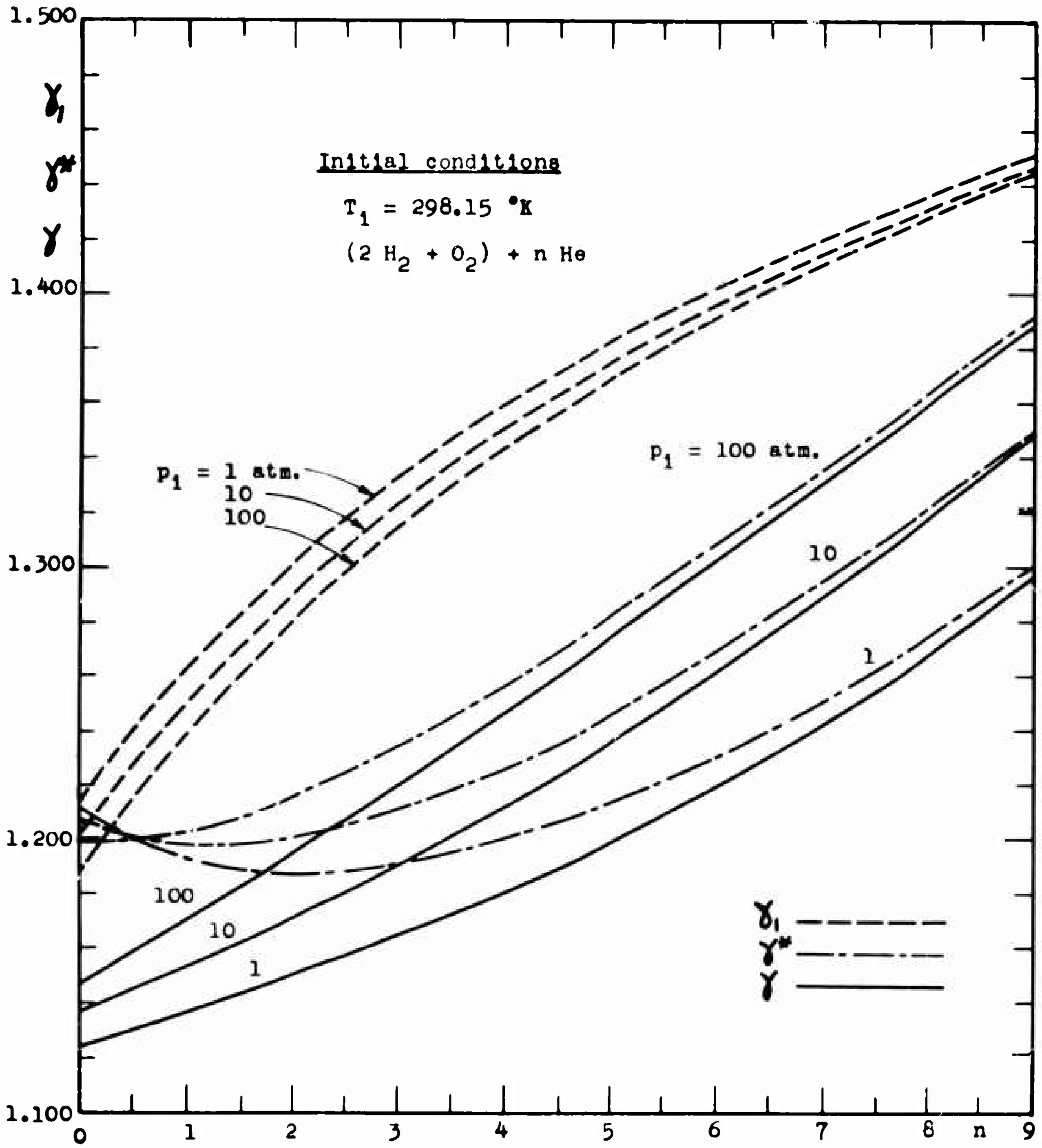

FIG. 3 SPECIFIC HEAT RATIO AND ISENTROPIC EXPONENT (HELIUM DILUTION)

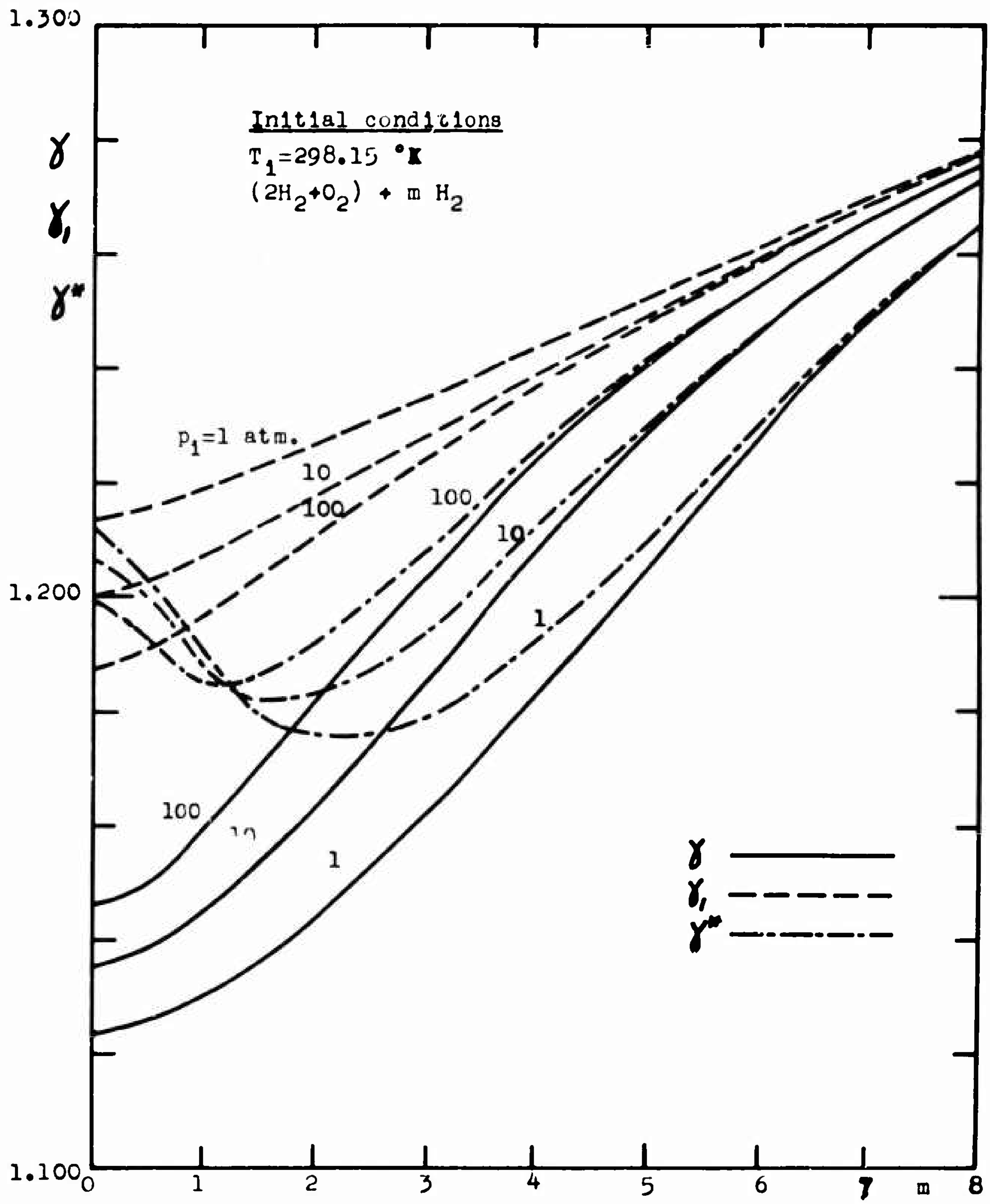

FIG. 4 SPECIFIC HEAT RATIOS AND ISENTROPIC EXPONENT (HYDROGEN DILUTION)

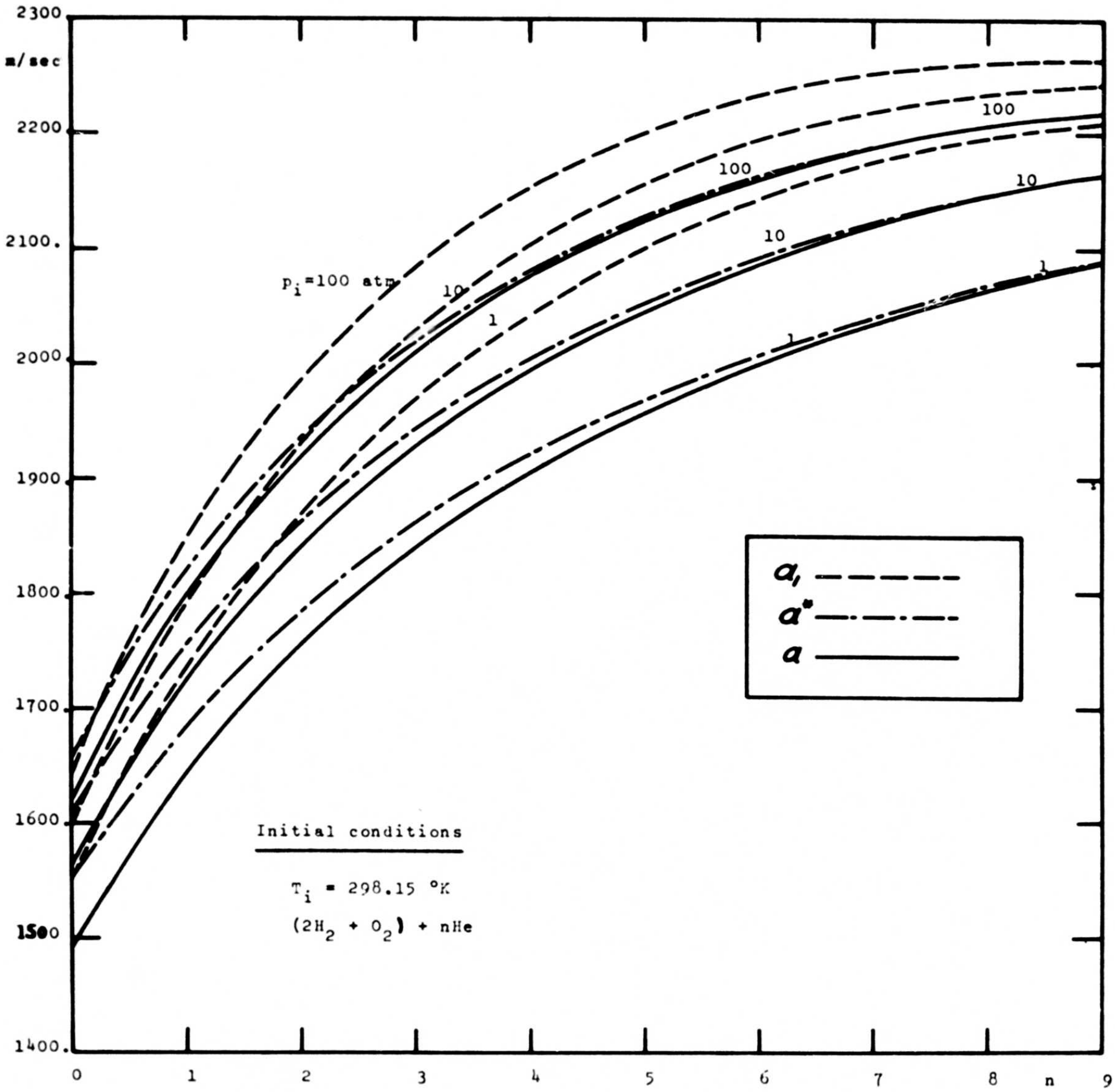

FIG. 5 SPEED OF SOUND VERSUS DILUTION (HELIUM DILUTION)

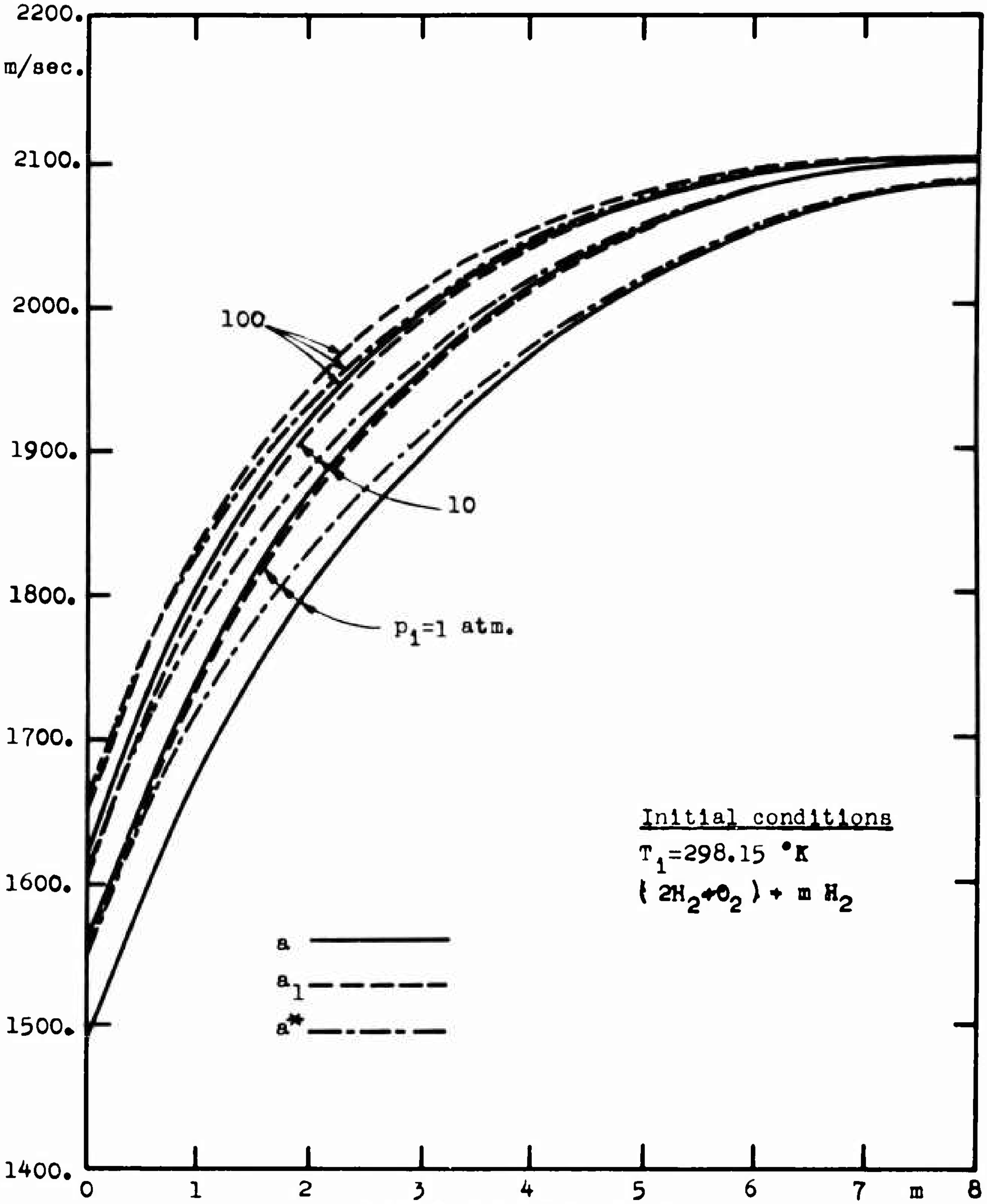

FIG. 6 SPEED OF SOUND VERSUS DILUTION (HYDROGEN DILUTION)

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SPECIFIC HEAT RATIOS AN D ISENTROPIC EXPONENTS FOR CONSTANT-VOLUME COMBUSTION OF STOICHIOMETRIC MIXTURES OF HYDROGEN-OXYGEN DILUTED WITH HELIUM OF HYDROGEN

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

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13. ABSTRACT

AD-455 747

This note is complementary to UTIAS Technical Note No. 85, "Thermodynamic and Composition Data for Constant-Volume Combustion of Stoichiometric Mixtures of Hydrogen-Oxygen Diluted with Helium or Hydrogen", by A. Benoit. It includes the calculation of the equilibrium specific heats, the equilibrium specific heat ratios, the isentropic exponents, and the corresponding values of the speeds of sound. For convenience, the final-to-initial temperature ratio and the final-to-initial pressure ratio ~~have~~ also ~~been~~ included in the present tables. The results are presented for helium and hydrogen dilution respectively.

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14. KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
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